TYPES OF ROCKY MOUNTAIN STRUCTURE IN SOUTHEASTERN IDAHO[1]

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INTRODUCTION

Since 1909 the United States Geological Survey has been making detailed studies of portions of the western phosphate field, chiefly in southeastern Idaho. This region contains a series of sedimentary rocks 40,000 feet or more thick, including large bodies of high-grade phosphate rock that will prove of great economic importance for the future, if not for the present. There is interesting geologic structure and a variety of problems covering a wide range of geologic and geographic phenomena.

[1] Read before the Geological Society of America, December 30, 1919; published by permission of the Director of the U.S. Geological Survey.

The area included in the detailed surveys is nearly 3,000 square miles comprised in the Fort Hall Indian Reservation, and in the Montpelier, Slug Creek, Crow Creek, Lanes Creek, Freedom,

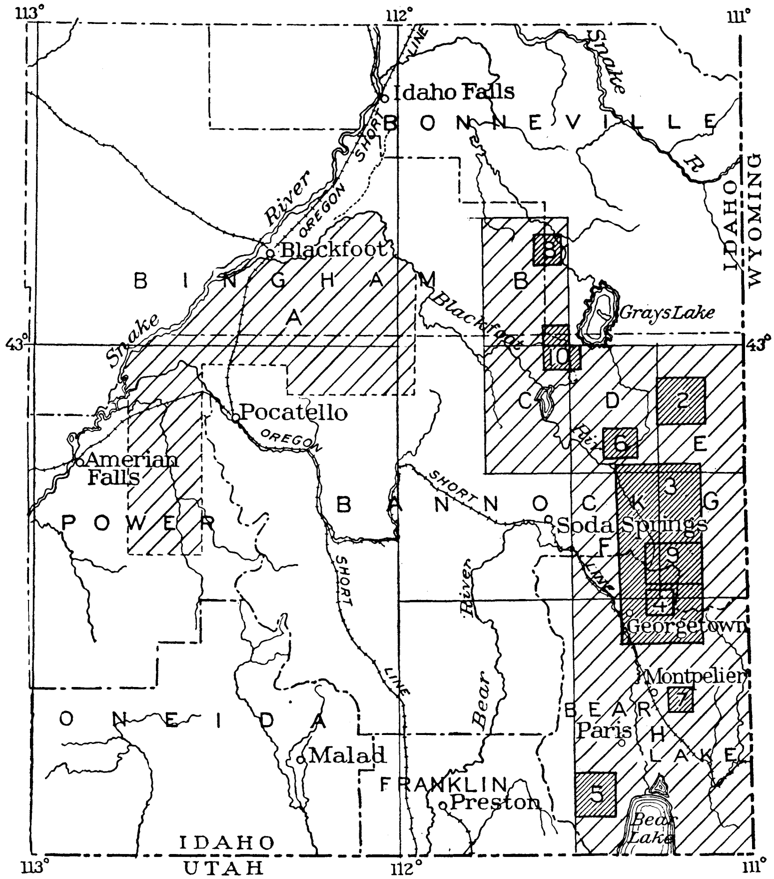


FIG. 1.—Index map of southeastern Idaho: *A*, Fort Hall Indian Reservation; *B-H*, seven quadrangles; *B*, Cranes Flat; *C*, Henry; *D*, Lanes Creek; *E*, Freedom; *F*, Slug Creek; *G*, Crow Creek; *H*, Montpelier. The areas lettered 2–10 are those illustrated by the corresponding figures.

Henry, and Cranes Flat quadrangles, all of which are fifteen-minute quadrangles except the Montpelier, which is a thirty-minute quadrangle. The location of these areas is shown on the accompanying map, Figure 1.

Three semi-detailed reports[1] and a number of shorter papers have already been published and a fourth report[2] is now in press. An additional, more extended report is well advanced in preparation and includes a discussion of the geography, geology, and mineral resources of the seven quadrangles named. The purpose of this paper is to present in advance of the detailed report some of the striking structural types of the region and to discuss briefly certain conditions that attended the development of these structures. The maps used in illustration of the structural features are extracted from the detailed geologic maps of the quadrangles mentioned. Their locations are shown on the index map, Figure 1.

GENERAL STRUCTURAL FEATURES

The stratigraphic series in southeastern Idaho includes more than sixteen recognized unconformities. Most of them do not appear to record great crustal disturbances, but a few indicate changes of considerable magnitude. Several are very striking, both as seen in the field and in cartographic representation

The region is traversed by many folds, some of which exceed 50 miles in length. The more important folds are synclinoria with relatively narrower intervening anticlines or anticlinoria, usually unsymmetrical and inclined or even overturned eastward or northeastward. The axes for long distances are nearly horizontal or slightly undulatory, due to the presence of relatively broad and low transverse folds, and the pitch is gentle, generally toward the north or northwest. The trend of the folds is convex toward the northeast, bending from a little east of north in the Montpelier quadrangle to northwest in the Lanes Creek quadrangle and beyond. This arrangement gives rise to long nearly parallel folds

[1] See especially H. S. Gale and R. W. Richards, "Preliminary Report on the Phosphate Deposits in Southeastern Idaho and Adjacent Parts of Wyoming and Utah," *U.S. Geol. Survey Bull. 430* (1910), pp. 457–535; R. W. Richards and G. R. Mansfield, "Preliminary Report on a Portion of the Idaho Phosphate Reserve," *U.S. Geol. Survey Bull. 470* (1911), pp. 371–451; R. W. Richards and G. R. Mansfield, "Geology of the Phosphate Deposits Northeast of Georgetown, Idaho," *U.S. Geol. Survey Bull. 577*, 1914.

[2] G. R. Mansfield, "The Geography, Geology and Mineral Resources of the Fort Hall Indian Reservation, Idaho, with a Chapter on Water Resources, by W. B. Heroy," *U.S. Geol. Survey Bull. 713*.

somewhat similar to those of the southern Appalachians. The Idaho folds, however, appear to be less regular in form than those of the Appalachian region. The intensity of the folding may be judged by the fact that within the region of the seven quadrangles mapped there are forty-two folds or groups of folds that have been considered of sufficient importance to receive names and to merit individual treatment in a detailed description of the region.

The influence of the transverse folds is seen chiefly in the widening or constriction of the longitudinal folds, in the production here and there of canoe- or cigar-shaped folds, and in the zigzag outcrop of certain formations, which cross the axes of the longitudinal folds.

The principal faults of the region are reverse and are doubtless chiefly associated with the Bannock overthrust, which has a length probably greater than 270 miles and a horizontal displacement certainly not less than 12 miles and perhaps greater than 35 miles. Normal faults are numerous and have produced a wide range of effects upon the pre-existing structures. Possibly some of the faults now regarded as reverse may prove to be normal. The intensity of the faulting is suggested by the fact that about sixty faults or groups of faults are sufficiently noteworthy to receive individual consideration in a detailed description of the region. About half of these are thrusts associated with the Bannock overthrust.

SPECIAL STRUCTURAL FEATURES

The structures to which attention is especially directed in this paper are (1) noteworthy unconformities; (2) "swallowtail" folds; (3) the Bannock overthrust; (4) the Blackfoot fault; (5) drag folds; (6) fan folds; and (7) the Meadow Creek graben. These will be described in the order named.

Noteworthy unconformities.—A very marked unconformity occurs in the southeastern part of the Montpelier quadrangle, where strongly folded Triassic and Jurassic beds pass beneath gently folded or nearly horizontal beds of the Wasatch formation (Eocene). This unconformity is the most striking of all the unconformities of the region. It represents at least the great post-Cretaceous mountain-building epoch of the northern Rocky

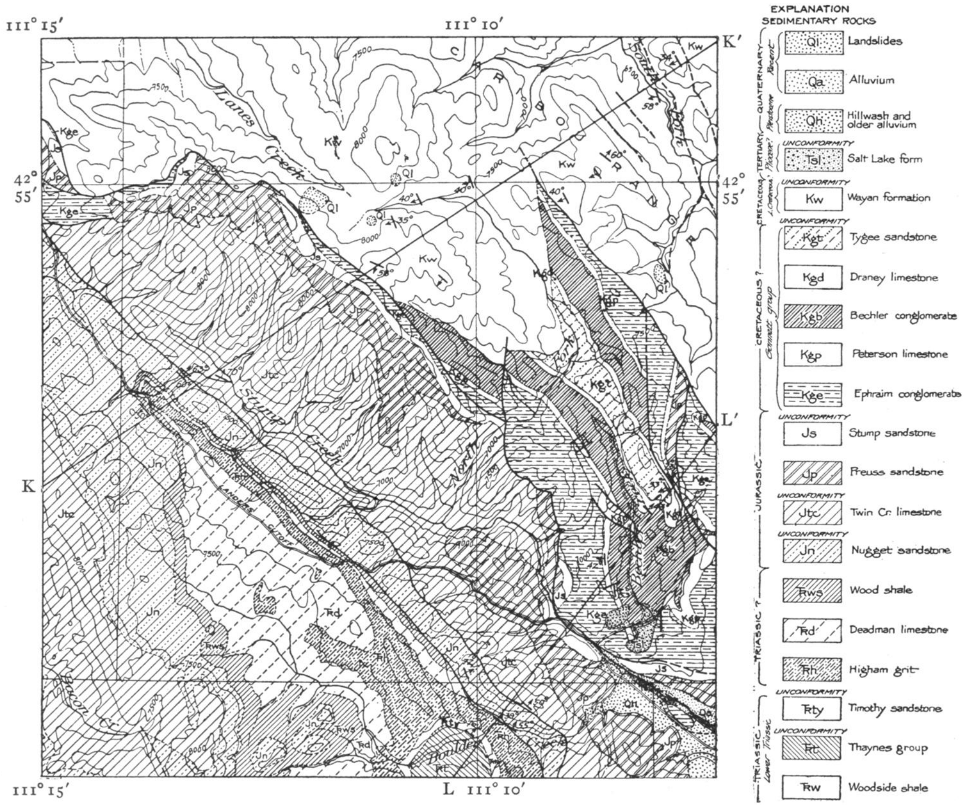


FIG. 2 *A*.—Map of part of the Caribou Range, Freedom quadrangle, showing the fault zone of the Bannock overthrust and the unconformity between the Wayan formation and the Gannett group.

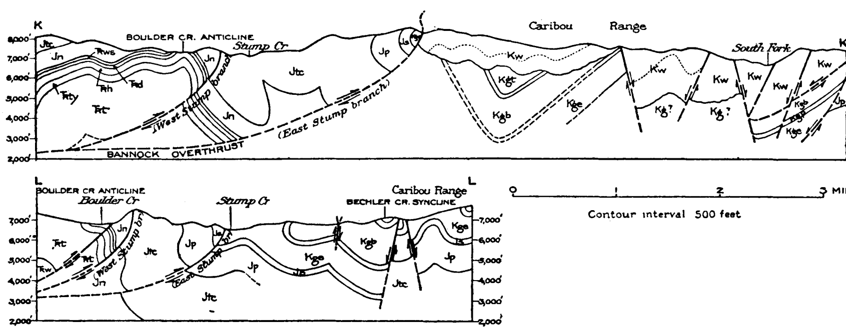


FIG. 2 *B*.—Sections along the lines *K–K'* and *L–L'* of Fig. 2 *A*

Mountains and a succeeding epoch of erosian long enough to remove all Eocene beds earlier than the Wasatch, if such were ever deposited, the Cretaceous formations, and two of the upper Jurassic formations.

A pronounced unconformity occurs between the Wayan formation and the underlying Gannett group, both of supposed Lower Cretaceous age. Figure 2 shows one of the localities where this unconformity appears. A syncline composed of members of the Gannett group is overlapped on the northwest by the Wayan formation, composed of beds folded in a manner comparable to that of the Gannett group but not yet differentiated into members. Another exposure of the same unconformity, perhaps even more striking, occurs about 3 miles east of the locality shown on the map.

"Swallowtail" folds.—These are folds in which the axes are nearly horizontal but are affected by cross folds in such manner that the outcropping formations as represented on the map resemble a swallow's tail. A remarkable group of folds having this form occurs in the Slug Creek and Crow Creek quadrangles, as shown in Figure 3, and has great economic importance because of its contained beds of high-grade phosphate. The group lies in the arc of curvature of the trend lines previously mentioned. A transverse syncline near the northern part of the area shown on the map causes the widening of the two lateral synclines and depresses the axis of the intervening anticline. It also causes the widening of the canoe-shaped fold partly shown in the northwestern part of the area. Other transverse axes cause the ending of the canoe-shaped fold and the changes in width of the middle and southern portions of the "swallowtail" folds. The axes of the transverse folds are roughly radial to the curvature of trend of the "swallowtail" folds.

The Bannock overthrust.—This great overthrust was first described in 1912.[1] Since that date the writer has had opportunity to extend his observations along the fault line and to secure new

[1] R. W. Richards and G. R. Mansfield, "The Bannock Overthrust: a Major Fault in Southeastern Idaho and Northeastern Utah," *Jour. Geol.*, Vol. XX (1912), pp. 681–707.

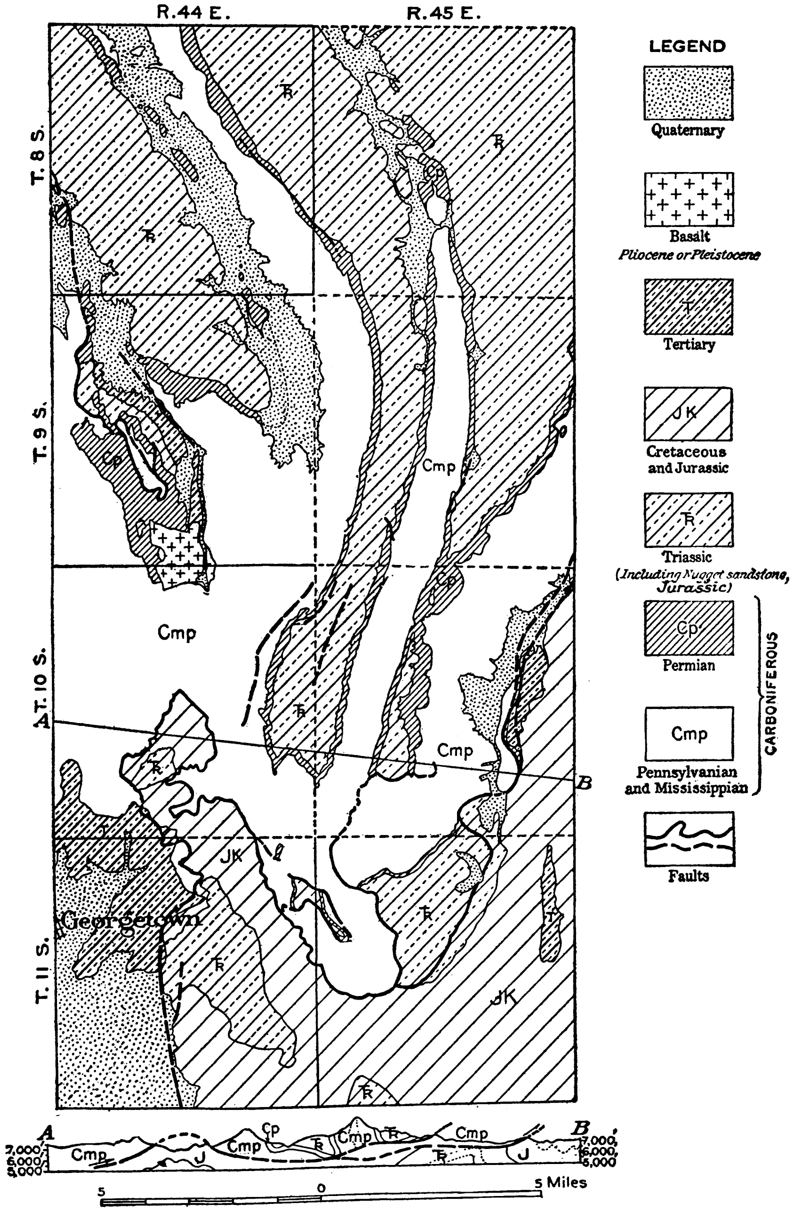


FIG. 3.—Map with geologic structure section of "swallowtail" folds in adjacent parts of the Slug Creek, Crow Creek, and Montpelier quadrangles, showing the folding and erosion of the plane of the Bannock overthrust, U.S.G.S.

data. The folding of the fault plane, previously announced, is well shown in Figure 3, both in plan and in section. Two aspects of this folding should be emphasized: (1) the folds of the fault plane are of a simpler and more open type than are those of the upper or lower fault blocks, as shown in the geologic structure section; (2) the fault plane previous to its deformation must have been nearly horizontal, else moderate folding would not have raised it to the level of erosion.

The underlying block is in most places composed of Mesozoic rocks more or less intensely folded, whereas the upper block is more largely composed of Paleozoic rocks that in the main are more competent strata. Mesozoic rocks, however, form part of the upper block at many localities. The relation of upper to lower block is shown in Figure 4, which represents the faulted area on the boundary line between T. 11 S., R. 44 E., and T. 11 S., R. 45 E., Figure 3. The fault there shown is regarded as a branch of the Bannock overthrust and is so represented on the map, but it may be a window in the main fault plane, as is supposed in the case of the area surrounded by a fault in T. 9 S., R. 44 E.

The Bannock overthrust is in some places a single fault plane, as in part of the area shown in Figure 3, but in other places it becomes complex and is really a fault zone composed of a number of rock slices separated by faults. Several branches are shown in Figure 3, and the branch that separates the Carboniferous from the Triassic rocks in T. 11 S., R. 45 E., is locally overturned and dips eastward. Three branches of the overthrust are shown in Figure 2. The East Stump branch, where crossed by the line of section KK', is practically vertical, but farther northwest it is overturned and dips northeastward. The West Stump branch, where crossed by the lines of sections KK' and LL', is also practically vertical, but at Boulder Creek it dips northeastward.

Figure 5 shows a complex portion of the fault zone near St. Charles, west of Bear Lake. There are probably no less than six faults which divide the rocks into roughly parallel slices east of the belt of Brigham quartzite, which is the easternmost formation of the upper fault block. The trace of the west branch of the fault in this district and southward lies east of a series of

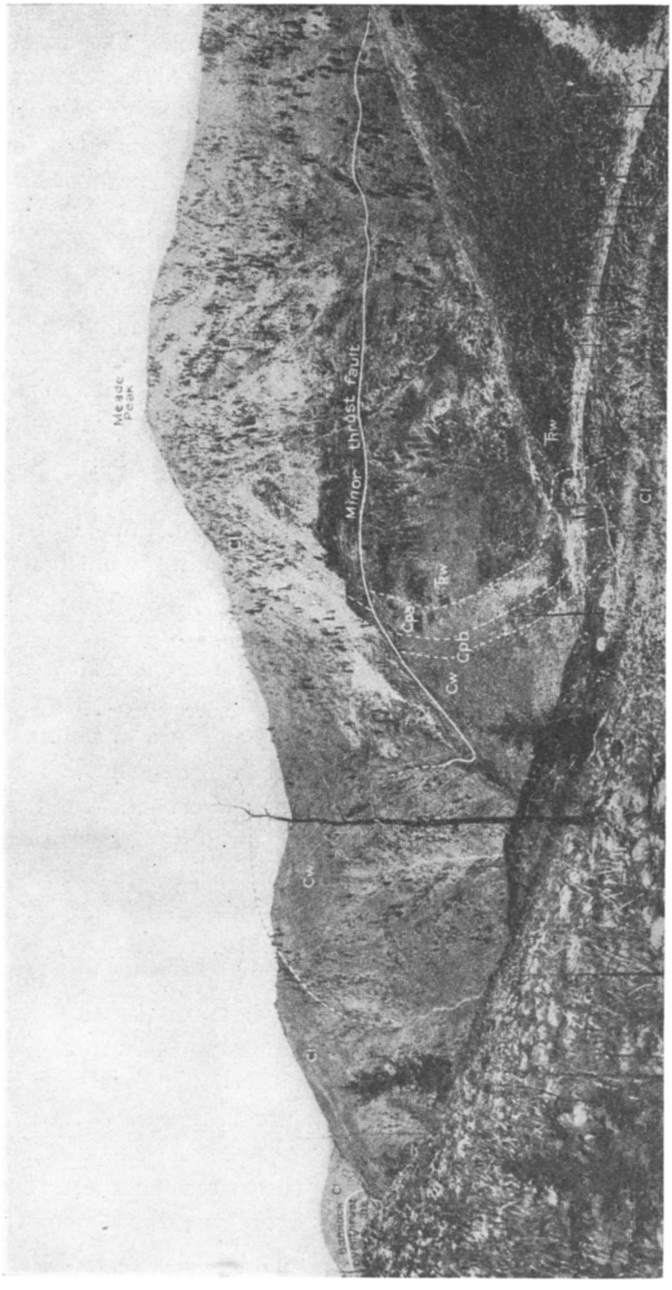


FIG. 4.—Meade Peak and South Canyon, from ridge in center of sec. 12, T. 11 S., R. 44 E. *C*1, Mississippian limestone; *Cw*, Wells formation; *Cpb*, phosphatic shales, etc. (Phosphoria formation); *Cpa*, Rex chert member of Phosphoria formation; *Trw*, Woodside shale; *Jtc*, Twin Creek limestone, U.S.G.S.

topographic sags and laps up on the west side of the adjoining hills. The upper fault block is composed of Cambrian and Ordovician formations, comprising the east limb of a syncline. The rock slices in the fault zone include at least a broken syncline of Ordovician

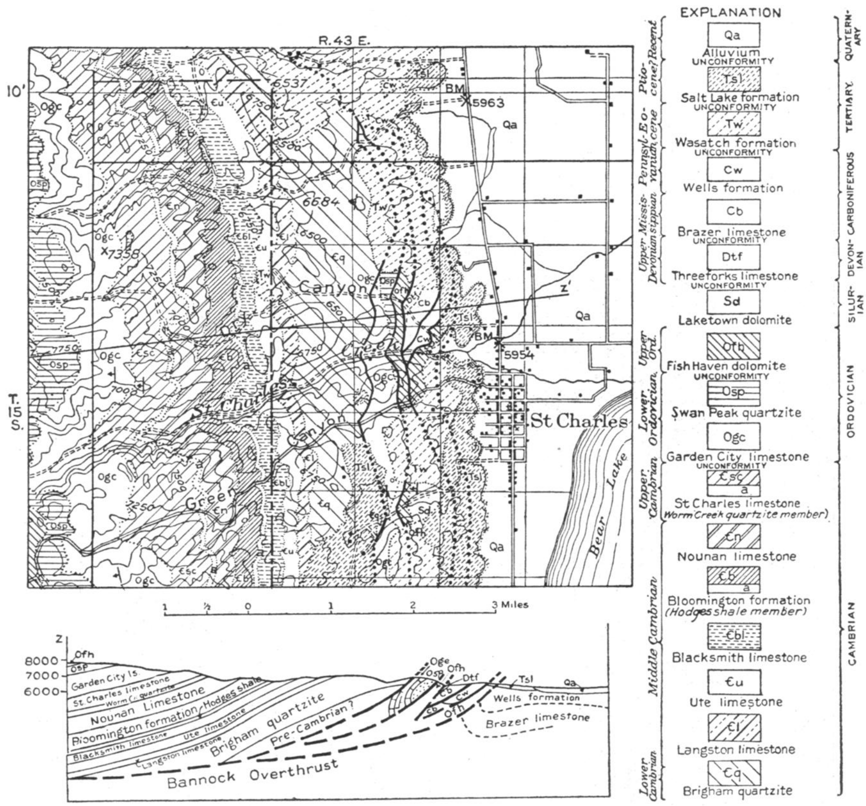


FIG. 5.—Map with geologic structure section of part of the Bear River Range, Montpelier quadrangle, showing the complex fault zone of the Bannock overthrust.

formations and parts of other folds containing Devonian and Carboniferous formations. The easternmost rock slice of the zone is probably composed of Fish Haven dolomite (Upper Ordovician). The structures east of the fault zone, along the line of structure section ZZ', are concealed by Tertiary beds and alluvium, but farther north scattering outcrops of the Wells formation (Pennsylvanian) occur east of this zone. It is thought, therefore, that the

synclinal structure east of the overthrust in the Bloomington-Paris district about 4 miles to the north may continue southward beneath

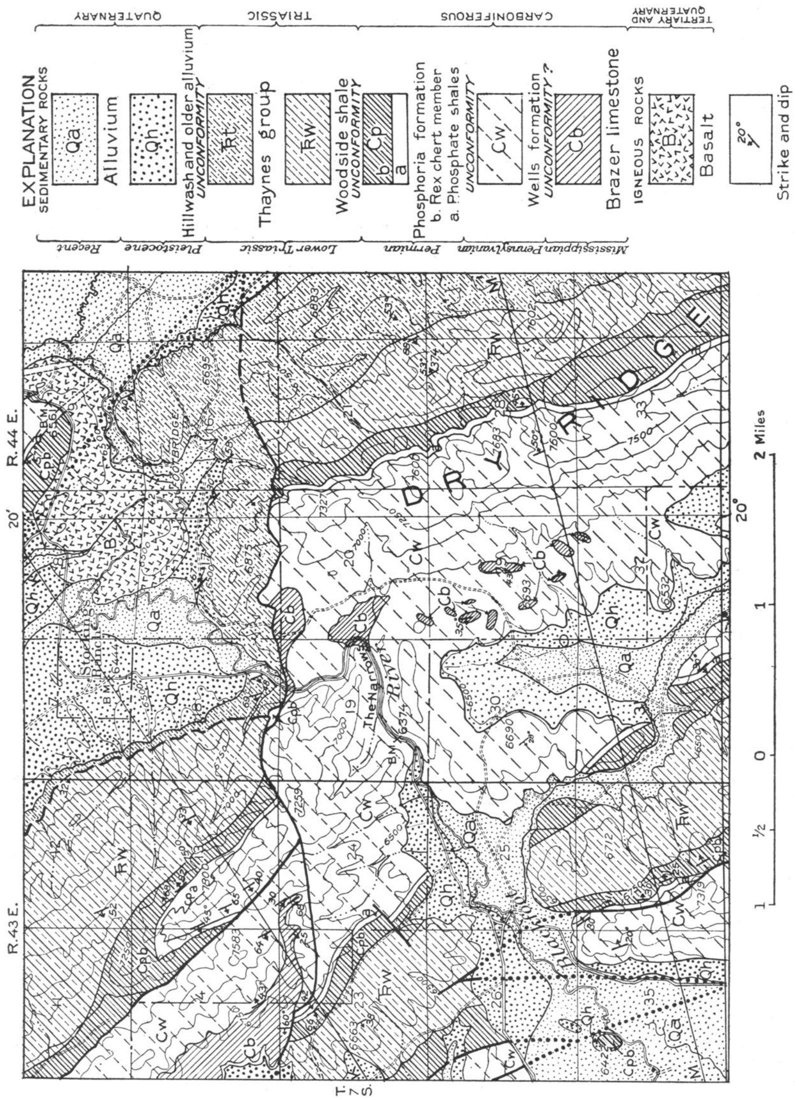


FIG. 6 *A*.—Map of part of the Preuss Range, Lanes Creek quadrangle, showing the Blackfoot fault and associated features.

cover. The dip of the thrust plane as a whole in the St. Charles district is probably gentle. A measurement in Paris Canyon about 6 miles north shows the dip at that locality to be 23°.

The Blackfoot fault.—This fault, which is illustrated in part in Figure 6, takes its name from the Blackfoot River, which it crosses at the upper entrance to the Narrows. The relations of the fault at this point indicate that its plane dips about 33° south. It is

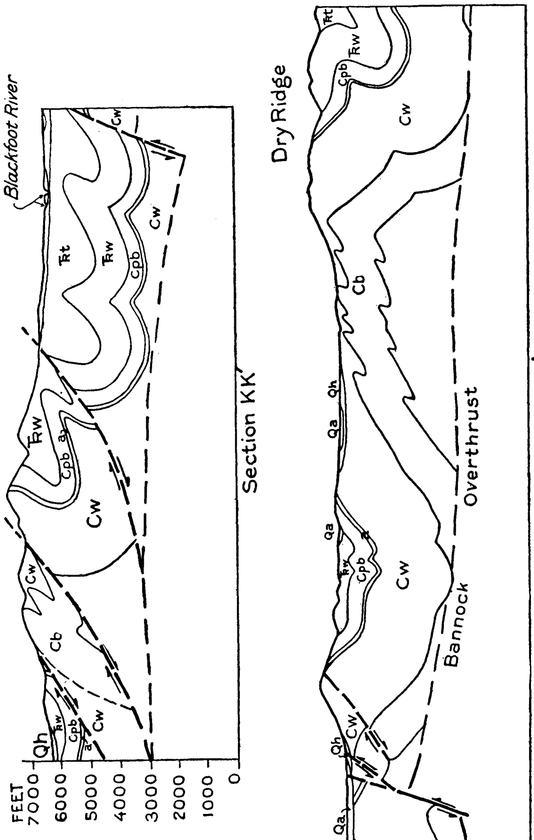


Fig. 6*B*.—Sections along the lines *K–K'* and *M–M'* of Fig. 6*A*

regarded as a thrust fault and is supposed to have originated in a transverse anticline, located near the line along which occurred the maximum yielding of the rocks to the compressive earth stresses of the region. The anticline broke and the southeast limb, which became the upper fault block, swung northward about a pivot located in the vicinity of Timothy Creek in the Freedom

quadrangle, about 5 miles east of the area illustrated. The rock formations cross this creek without apparent displacement by the fault, but they make a pronounced bend, which is favorably located to mark the position of the unbroken portion of the axial zone of the anticline.

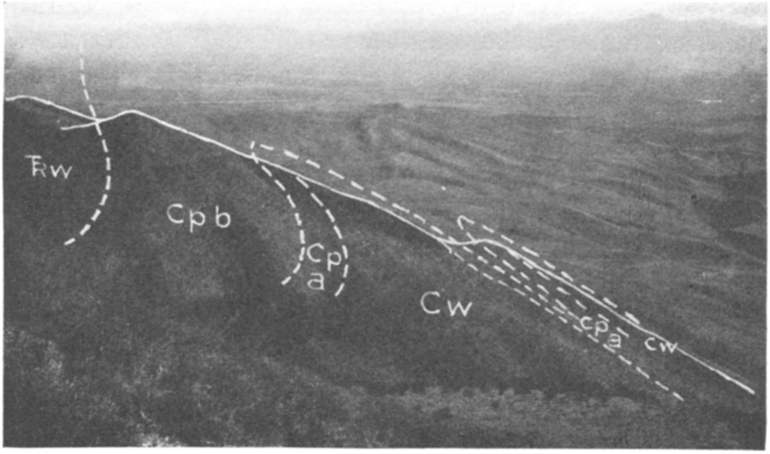
The Blackfoot fault has a known length of about 13 miles westward from the point of origin above indicated. At this distance it disappears beneath basalt. The variations in dips on the flanks of the big anticline in the upper thrust block, some of the strata being locally overturned, and the presence of minor folds, make it difficult to determine the throw of the fault. The maximum observed effect is produced where it cuts the big anticline. The fault is probably offset beneath cover by one of the normal faults shown in the southwestern part of the area.

The upper fault block affords an unusually fine example of the manner in which the outcrops of a formation, such as the Phosphoria, occurring on opposite limbs of an anticline, are spread by the uplift and erosion of a fault block, in which the anticline is included. In the lower block to the north the corresponding outcrops are much nearer together.

The structure section along the line *KK′* crosses the Blackfoot fault. It shows the anticlinorial and synclinorial character of the folds, their overturning toward the northeast, and the manner in which some of the subsidiary thrusts are thought to have originated. The thrusts are presumed to pass into the Bannock overthrust, which underlies this district.

Drag folds.—Folds of this type, usually sharp and unsymmetrical, occur at a number of places in the region. Several of them are shown in Figure 6 in connection with the big anticline in the upper fault block. One of them is crossed by the line of structure section *MM′*. Here upper beds of the Brazer limestone (Mississippian) in small sharp folds are locally exposed by the erosion of the overlying Wells formation.

Drag folds on a somewhat larger scale occur on the hills south of Montpelier Canyon about 3 miles east of Montpelier. In Figure 7*A*, a view south along the west flank of Waterloo hill shows an anticline overturned eastward in which curving beds of



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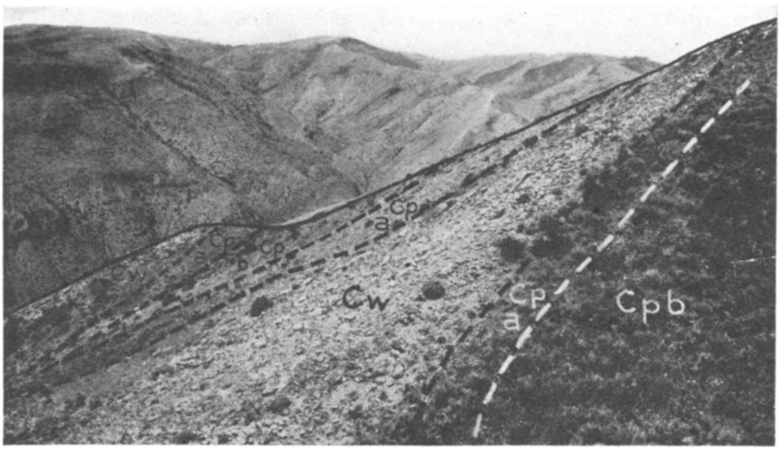

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FIG. 7.—*A*, View south along west flank of Waterloo Hill about 3 miles east of Montpelier, Idaho, showing drag folds accompanying large unsymmetrical anticline; *B*, view of same folds northward from different viewpoint, showing west flank of the same anticline. *Cw*, Wells formation, Pennsylvanian; *Cpa*, phosphatic shale member of Phosphoria formation, Permian; *Cpb* Rex chert member of the Phosphoria formation, Permian; *Trw*, Woodside shale, Lower Triassic.

the Rex chert member of the Phosphoria formation (Permian) form the east limb of the anticline and indicate the occurrence of a syncline farther east. In the middle of the view is a sharp anticlinal fold inclined eastward. Near the base of the slope at the right (west) is another drag fold, very sharp and inclined eastward. These drag folds are composed of upper beds of the Wells formation and of the overlying phosphatic shales of the Phosphoria formation, which are relatively less competent than the Rex chert above or the bulk of the Wells formation below. The effect of the drag folds is to duplicate the outcropping beds of phosphatic shales, which appear as separate bands on the hillside. The anticline, of which the drag folds form a part, is largely eroded, but its west limb is exposed in a branch canyon to the north. Figure 7*B* is a view north from a somewhat different viewpoint. It shows the westerly dipping beds of the west flank of the anticline and the same two drag folds illustrated in the previous view.

Fan folds.—Folds of this type have been recognized at several places in the region. Usually they are so deeply eroded that only their stumps remain, or they are broken by faults. In the vicinity of Sugarloaf Mountain, however, in the Cranes Flat quadrangle, see Figure 8, there is a fine example of an inverted fan fold. The rocks immediately involved belong to the Homer limestone member of the Wayan formation (Lower Cretaceous?).

Sugarloaf Mountain was selected by St. John[1] of the Hayden Survey years ago as a station, and he drew a geologic structure section through it, in which he shows a southwesterly dipping series of strata, overlapped on the west by basalt at Sheep Mountain just west of the area shown in the figure, and arched into a prominent anticline at Sugarloaf Mountain by an igneous intrusion. The structure of the area near Sugarloaf Mountain is not so simple as figured by St. John. The limestone, which he did not differentiate from the other strata, is there thrown into a series of relatively sharp folds, among which narrow folds of the underlying sandstone rise to the level of erosion here and there. Southwest of Sugarloaf Mountain the dips of the limestone and the related strata are

[1] Orestes St. John, "Report of the Geological Field Work of the Teton Division," *U.S. Geol. and Geog. Survey Terr.* (*1877*), *1879*, pp. 351–60.

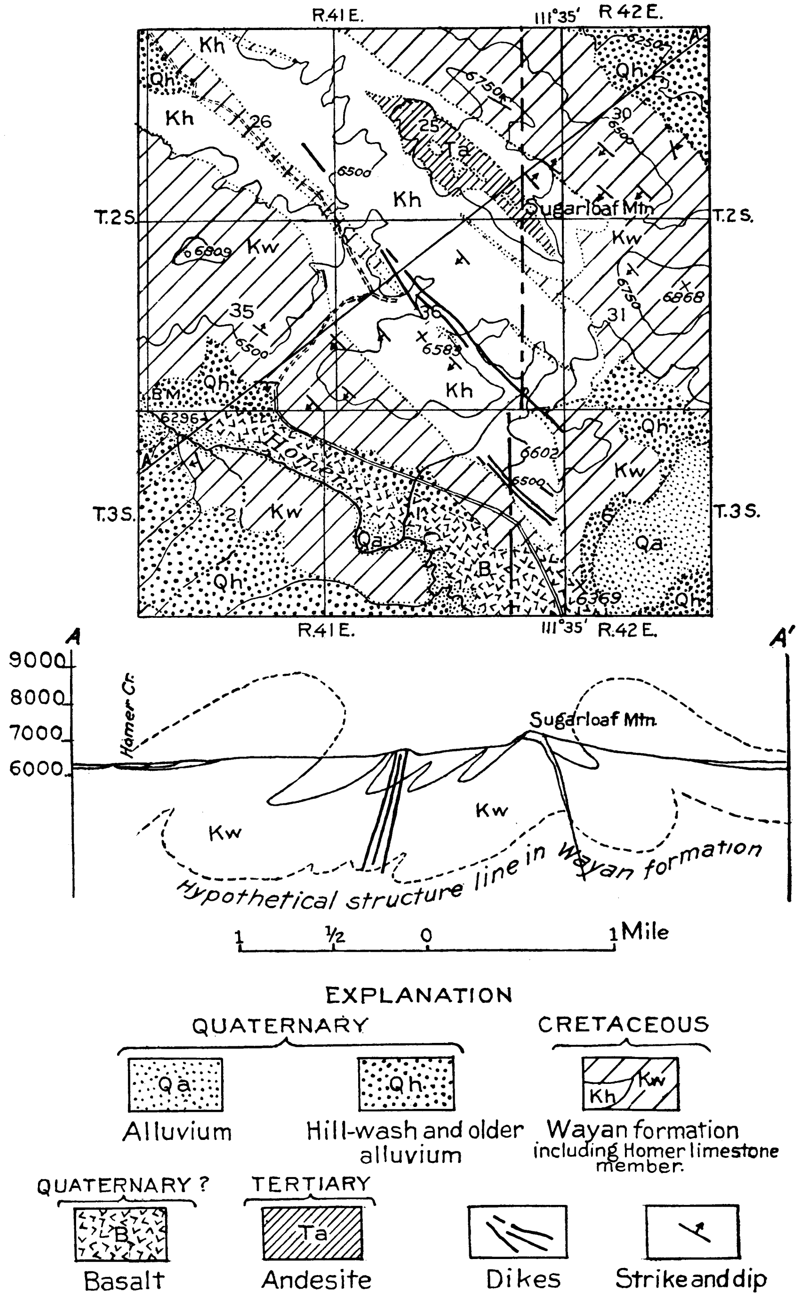

FIG. 8.—Map with geologic structure section of the Sugarloaf district, Cranes Flat quadrangle, showing an inverted fan fold.

southwest, but northeast of the mountain the dips of the limestone are northeast. Thus the structure of the limestone is a synclinorium, having the general form of an inverted fan fold. The intrusion at Sugarloaf Mountain is a thickened sill or incipient laccolith, arching with the strata in the northwestern extension of the mountain but eroded on the southwest limb beneath the summit and southeastward. The fold which forms the mountain is one of the subordinate folds of the synclinorium rather than a major structural feature supported by a relatively large intrusive body, as postulated by St. John. The geologic structure section AA' illustrates the features described above. Its line forms an angle of about 30° with that of St. John's section.

An example of what is believed to be the stump of an upright eroded fan fold is found in the western part of the Crow Creek quadrangle, see Figure 9. Snowdrift Mountain, part of one of the most persistent anticlines of the region, is flanked on either side by synclines which are in general inclined eastward. The Webster syncline on the east is markedly unsymmetrical, the west limb being steep and locally overturned eastward, but the east limb has a gentle westerly dip. The Georgetown syncline along the west side of Snowdrift Mountain is deeper and the limbs are steeper. The east limb is locally vertical or even overturned. Thus the intervening Snowdrift anticline is with little doubt an eroded fan fold. The structure sections along the lines SS' and TT' illustrate the features cited. At the line SS' the axis of the fan fold is somewhat inclined eastward and the Webster syncline is broken by a local thrust. Although the Snowdrift anticline does not everywhere show a tendency toward fan folding it is closely folded throughout most of its length and here and there exhibits that tendency, as shown on the west flank of Pelican Ridge, see structure section GG', Figure 10*B*. The Dry Valley anticline, west of the Snowdrift anticline, see section SS' Figure 9*B*, locally has similar tendencies. Other instances which may not be figured here are illustrated in the forthcoming detailed report.

The Meadow Creek graben.—Perhaps the most striking effect of normal faulting in the region is the production of horst and graben structure in the northwestern part, see Figure 1c. The

valley of Meadow Creek in the southern part of the Cranes Flat quadrangle is a fault trough or graben. This structure may be traced about 15 miles southeast into the Lanes Creek quadrangle, where it apparently dies out. The northward extension of the graben is concealed by basalt and Quaternary deposits. The bounding ridges are composed of Carboniferous rocks and are conspicuous topographic features.

Two transverse normal faults intersect the graben, one near the south boundary of the Cranes Flat quadrangle and the other in the northwest corner of the Lanes Creek quadrangle, down-faulting the portion between them. The bounding ridges in the down-faulted area are farther apart than in the portions to the northwest or southeast. In the southeastern part of the graben beds of the Thaynes group (Lower Triassic) are exposed and in the widened, down-faulted portion both the Woodside shale (Lower Triassic) and Thaynes appear, though most of the area is underlain by basalt and Quaternary deposits. The structure of the rocks within the graben is probably synclinal, as shown in structure sections *EE′* and *GG′*. It is with little doubt the continuation of synclinal structures observed farther southeast.

The fault which lies along the northeast side of the graben is concealed for much of its length, but in the southeastern part of the area here shown is represented by two faults, separated by a narrow strip of the Phosphoria formation, but together bringing Lower Thaynes into proximity with the Wells. Northwest of the area illustrated the fault doubtless continues for some distance beneath the basalt. Its stratigraphic throw is not known but is estimated at 3,000 to 4,000 feet.

The transverse normal fault that passes between Limerock Mountain and Pelican Ridge causes the mountain to stand nearly a mile northeast of the line of continuation of the ridge. Similar effects in reverse order are produced where the fault intersects Little Gray Ridge. Neither the amount of the downthrow nor the hade of the transverse fault is known, but from the effects and assumed values for the dips of the lateral faults that bound the graben it is thought that 5,200 feet may represent the order of magnitude of the vertical displacement.

The other transverse normal fault intersects the graben southeast of Pelican Ridge. Its generally east-northeasterly course is largely concealed by basalt, but it cuts across Little Gray Ridge

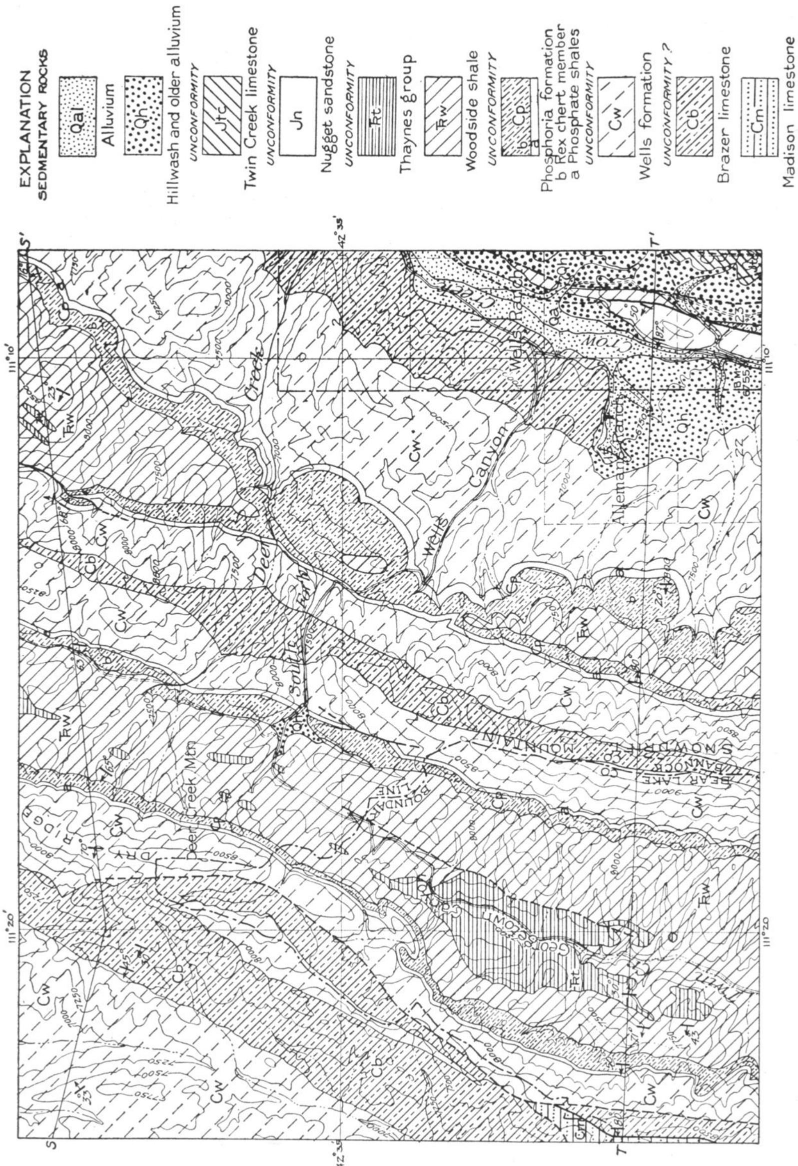

FIG. 9A.—Map of parts of the Preuss Range, Slug Creek, and Crow Creek quadrangles, showing eroded fan folds and associated features.

and there offsets the boundary between the Brazer and Madison limestones (Mississippian). Basalt has outflowed on the west flank of the ridge along part of the fault trace. The downthrow

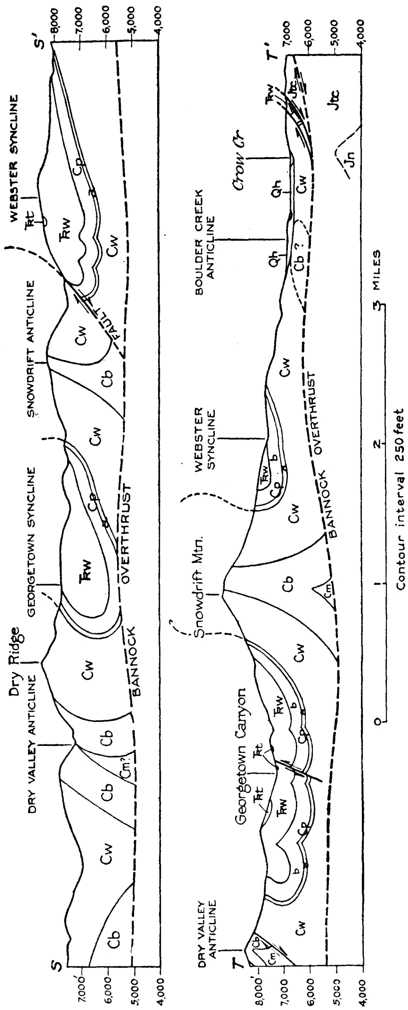

FIG. 9B.—Sections along the lines S–S' and T–T' of Fig. 9A

is to the northwest and, employing similar assumptions to those noted for the last described fault, an estimate of 3,500 feet may be made for the vertical displacement at this locality.

The faulted ridge including Limerock Mountain and Pelican Ridge, a continuation of the Snowdrift anticline mentioned above, is here a horst, for it stands between the Meadow Creek graben on

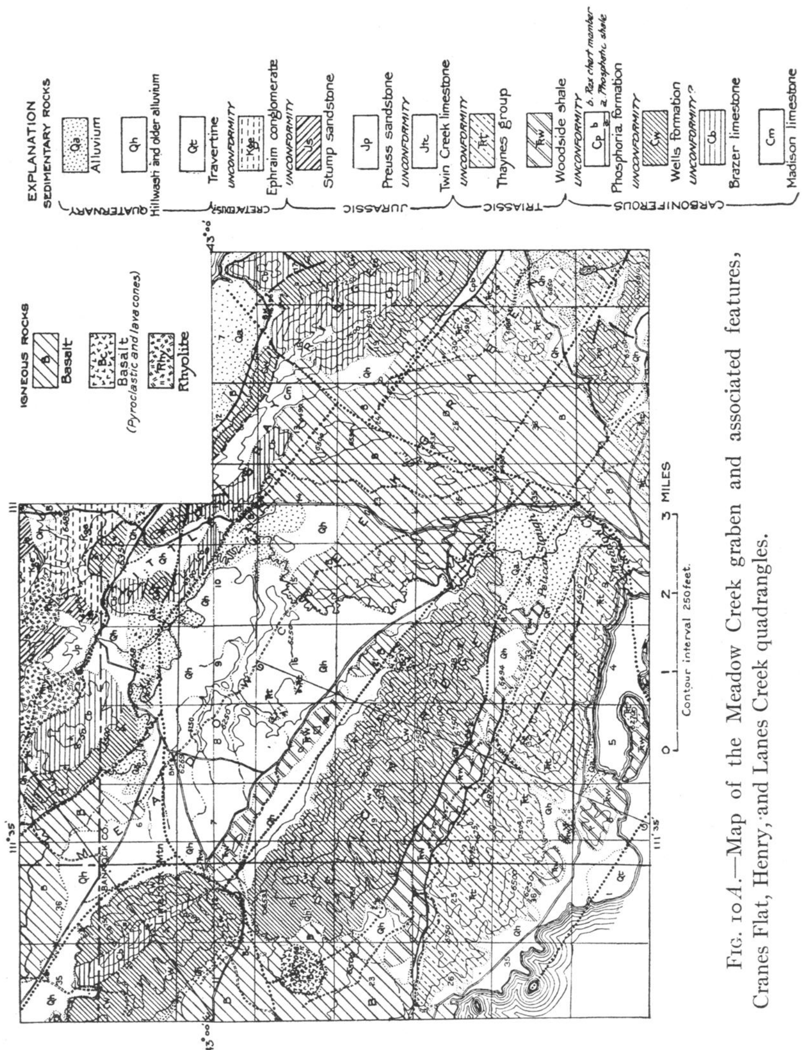

FIG. 10A.—Map of the Meadow Creek graben and associated features, Cranes Flat, Henry, and Lanes Creek quadrangles.

the northeast and another down-faulted area on the southwest. The relations of this horst to the adjoining areas, both northeast and southwest, are shown in structure sections *EE′* and *GG′*.

The ridge northeast of the graben is not clearly a horst though it is much broken by faults and has suffered extrusion of rhyolite.

NOTES ON THE DEFORMATION OF SOUTHEASTERN IDAHO

Epochs of deformation.—Although southeastern Idaho was profoundly affected by crustal disturbances at the close of the Jurassic, the observed mountain structures appear to be the result of two later epochs of mountain building. The earlier of these occurred after the deposition of the Wayan formation and before the deposition of the Wasatch formation. It probably corresponds

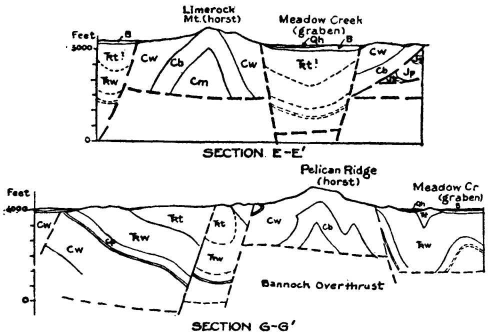

FIG. 10*B*.—Sections along the lines *E–E′* and *G–G′* of Fig. 10*A*

with the interval between the Adaville and Evanston formations of Veatch[1] or the epoch which, according to Ransome,[2] "appears to have begun at the close of the recognized Laramie or possibly even earlier, and to have attained its maximum between the Fort Union, which chiefly on the basis of its plant remains is generally classed as basal Eocene, and the mammal-bearing lower Eocene Wasatch."

The second mountain-building epoch occurred after the deposition of the Salt Lake formation which, on the basis of present rather unsatisfactory evidence, is tentatively assigned to the Pliocene. This formation locally has steep dips thought to have been produced by deformation in late Pliocene or post-Pliocene time.

[1] A. C. Veatch, "Geography and Geology of a Portion of Southwestern Wyoming," *U.S. Geol. Survey Prof. Paper 56* (1907), p. 75.

[2] F. L. Ransome, "The Tertiary Orogeny of the North American Cordillera and Its Problems," *Problems of American Geology*, pp. 287–376, p. 322, New Haven, 1915.

Rocky Mountain geosyncline.—Southeastern Idaho forms a part of a great geosyncline in which sediments were deposited with few interruptions of magnitude from early Cambrian to Upper Cretaceous times. This great trough extended from the Arctic Ocean southward through the Great Basin and was in general an area of subsidence or a negative element[1] on which the sediments had accumulated in great thickness. On the west during the same interval a relatively persistent land mass or positive element had separated the geosyncline from the Pacific Ocean, and on the east a less persistent barrier at times had separated it from the interior sea.

The geosyncline served to localize the deformation and had a directive influence upon it. The tangential pressure which produced the folds and overthrusts was normal to this structure and, in southeastern Idaho, came from the west southwest.

Initial dips within the geosyncline and differences in the character of the sediments doubtless tended still further to localize the folds and thrusts and to determine their character.

Favorable formations.—Many of the Paleozoic formations are massively bedded and would act as competent strata under deformation. A number of formations, however, contain shaly members. Some of the limestones, too, are thin bedded. Such formations exposed to deformation in the zone of fracture would furnish horizons in which thrust planes might originate. The Bannock overthrust zone is complex and no one formation has yet been identified as the source of the thrust plane.

The Mesozoic formations are generally weaker and less well consolidated than are the Paleozoic rocks. Lying with favorable initial dip and in great thickness athwart the direction of maximum compression, the Mesozoic rocks crumpled under the accumulating compressive stress and permitted the more or less folded Paleozoic rocks with some accompanying or overlying Mesozoic rocks to override them. They thus generally form the basement over which the great thrust block of the Bannock overthrust moved and on which it now rests. Although it has been customary in

[1] Bailey Willis, "A Theory of Continental Structure Applied to North America," *Bull. Geol. Soc. America*, Vol. XVIII (1907), pp. 389–412.

the discussion of overthrusts to regard the lower block as passively overridden by the upper or thrust block, it is probable that both participate in the movement, the separated parts moving past each other, as suggested by Barrell.[1]

Horizontal thrusting.—The original nearly horizontal attitude of the Bannock thrust plane has been modified by subsequent compression and folding, but it indicates that the effective deformative forces acted horizontally and were not the surface expression of obliquely emerging, deep-seated shear, such as was postulated by Willis[2] for the fault zone along the east side of the Sierra Nevada Mountains.

Factors in deformation.—Chamberlin and Miller[3] have shown from their own experiments and from the earlier work of Cadell, Willis, Adams, and others that many factors are involved in the production of low-angle faulting, such as is exemplified in great overthrusts. Among these may be mentioned: (1) rotational strain; (2) increase in resistance to deformation with depth; and (3) a relatively large ratio of thrust to weight.

(1) Rotational strain as a factor in the deformation of southeastern Idaho is clearly indicated by the frequency of inclined or overturned structures.

(2) Although no data are available regarding conditions in depth, it is clear from the horizontality of the thrusting previously mentioned and from the locally fractured and generally unmetamorphosed condition of the strata, that the deformation took place at no great depth. The visible structures at least were developed in the zone of fracture. No evidence of flowage has been found.

(3) The great horizontal displacement produced by the Bannock overthrust shows that the thrust was enormous. The weight, on the other hand, could not have been very great because of the apparent shallowness of the deformation.

[1] Joseph Barrell, "The Upper Devonian Delta of the Appalachian Geosyncline," *Am. Jour. Sci.* (4th ser.), Vol. XXXVII (1914), p. 107.

[2] Bailey Willis, "Structure of the Pacific Ranges, California," *Bull. Geol. Soc. America*, Vol. XXX (1919), pp. 84–86.

[3] R. T. Chamberlin and W. Z. Miller, "Low-Angle Faulting," *Jour. Geol.*, Vol. XXVI, No. 1 (1918), pp. 1–44.

Later deformative epoch.—The later epoch of deformation was marked by broad uplift rather than by intensive folding. There was, however, some folding, involving locally steep or overturned dips, but generally of an open character. The folding of the plane of the Bannock overthrust is of this type and is thus structurally more akin to the later than to the earlier deformative epoch.

Relaxation and readjustment.—The vigorous compression of the earlier deformative epoch was succeeded by relaxational phases involving normal faulting and gradual readjustment to new conditions of equilibrium. Some normal faults along the Bannock fault zone represent with little doubt the fracture and jostling of blocks under light load near the margin of the fault block. Other normal faults partly concealed by Tertiary beds also may be referred to the interval of relaxation following the earlier deformative epoch. Many of the normal faults, however, including those that produced the horst and graben structure, are not associated with Tertiary beds. There is a single doubtful exception to this statement. On the other hand there is definite evidence that Tertiary beds have been displaced by normal faults. Thus these faults have been considered as later than the Tertiary beds but earlier than the earliest Quaternary, and hence associated with the relaxational interval succeeding the later deformational epoch.

The horst and graben structure is more or less intimately associated with extrusions of ryholite and basalt. The basalt in particular has flooded the valleys in the vicinity of these structures and has emerged along some of the fault lines. On the other hand, sufficient erosion had occurred after the faulting to produce practically the present topography before the extrusion of the basalt. That event, therefore, probably accompanied a relatively late reopening of some of these faults, together with the development of new fissures.

At present no definite evaluation of the parts to be assigned to the two relaxational intervals may be made.